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241. *Validity of Estimates.*

All estimates of this character are, of course, only provisional, and they can claim no validity, as I have heretofore shown, beyond the accuracy with which they represent the data upon which they are based. That all the æthereal elements which I have considered are important, that they are more far-reaching than those which have been introduced into any like discussion of which I have any knowledge, that their influence has been rightly stated, and that they will contribute, by collation with Thomson's and other estimates, to a more satisfactory solution of many physical problems than is yet attainable, I fully and unhesitatingly believe. Sun's orbital motion, and questions connected with the retardations which change revolution into simple rotation, are among the considerations which seem likely to modify the values that are given in the five foregoing notes and in Note 35.

Note on the Aurora of April 16-17, 1882. By H. Carvill Lewis.

(Read before the American Philosophical Society, April 21, 1882.)

The aurora of Sunday evening, April 16-17, 1882, was probably one of the most remarkable, both as to beauty and scientific interest, that has been observed in this latitude. It is especially noteworthy on account of the brilliant *corona* which continued well defined for several hours, and whose apparent motion eastward, through space, could, therefore, be determined. Several other unusual features, such as an *auroral curtain*, and hyperbolic curves of light, were also displayed. The attendant solar and magnetic phenomena have also been of great importance in determining a theory of the aurora.

The aurora was noticed as soon as twilight had ended as a faint glow along the northern horizon. At 8.30 it was a low arch, probably not over 10 degrees high. It gradually rose higher, and left a dark segment below it. At 10 P. M. the arch was some 20 degrees high, and was constantly increasing in brilliancy. Bright short white acicular streamers now appeared in the north, and sometimes rose as high as 40 degrees. These occasionally assumed a reddish color, and were frequently wafted along the arch towards the west. The aurora now fluctuated greatly in brilliancy, sometimes nearly disappearing, and then flashing out brighter than ever.

At 11.15 the arch had become brighter and much longer, though still of low altitude. Bright acicular streamers were crowded closely together at the western end of the arch, while in the east a second arch was now formed. The auroral arch now began to rise rapidly. At 11.20 the upper arch was 40 degrees high. Long narrow streamers were rapidly forming over the whole northern sky, and were traversed from base to apex with

swift, tremulous waves of light. At the same time a mass of fine red color appeared in the north-west, and flashed alternately bright and dark, as though a red cloud illuminated by heat lightning. This mass of red color moved rapidly westward and was preceded by remarkable flashes of red. At 11.25 the aurora had risen nearly to the zenith, and was of great brilliancy. Numerous narrow streamers, covering the entire northern half of the sky, were flashing bright and dark with great rapidity, while fine crimson patches appeared independently in several portions of the sky.

At 11.30, or a few minutes later, the whole aurora from all sides moved with a bound toward the zenith. Streamers shot up from north, east and west with rapid, tremulous motions, reaching higher and higher with each pulsation, until, after apparently several ineffectual attempts, they all converged at a point nearly on the meridian nineteen degrees south of the zenith to form a corona of great beauty. This corona, which at first was unsteady and continually broken into detached segments, had become, at 11.40 P. M., a constant feature. Streamers now radiated from it in every direction, south as well as north. The whole sky seemed in motion except this one point. Rapid waves traveled along the narrow streamers from the horizon nearly up to the corona, while great nebulous masses and broad bands of crimson light flashed out in different portions of the sky. These masses of red light, particularly noticeable in the north-west, had no definite form, and showed no undulating pulsations like those of the thread-like streamers, but either hung steadily in the sky for some minutes, or else were illuminated with flashes like lightning. The impression was given that these red portions of the aurora were distinct phenomena, disconnected from the greenish-white streamers, and, perhaps, at a greater distance from the earth.

The centre of the corona appeared to be some 12 degrees east of Arc-turus. At 11.50, the centre of the corona was estimated to have the position R. A. 204° , Dec. $21^{\circ} 30'$.

At midnight the corona, a perfect star of light, had become wonderfully beautiful. The brilliancy of the whole aurora was concentrated at this point, the horizon being comparatively dark. Remarkable coruscations of light surrounded the corona, and these were often curved so as to approach in form a hyperbola of large eccentricity, whose transverse axis passed through the centre of the corona. The streamers between the corona and the northern horizon now united into remarkable concentric hyperbolic curves of great brilliancy, whose vertices were stationary near the corona, and whose tremulous arms, made up of many streamers, reached to the northern horizon. This form recalled the drawings made of the coma of certain comets, and suggests interesting analogies.

Still more closely did these curves of light resemble those assumed by iron filings in the vicinity of a magnet, and it is probable that they were identical.

The centre of the corona was now at R. A. 207° , Dec. $21^{\circ} 30'$.

At 12.10 A. M., and during the half-hour following, occurred the most magnificent sight of the evening, to which no description can do justice. The streamers, whose mass was now concentrated in the corona, had detached themselves from the northern horizon to form an *auroral curtain* of great beauty. The curtain hung some twenty degrees above the horizon, and was continually changing in form and color. The streamers, whose lower ends formed its fringe, were united above in bright hyperbolic or magnetic curves, which approached the corona within ten degrees, and which remained constant while the lower part of the curtain waved to and fro in waves of light.

The following very rough diagram may serve to illustrate the general positions of the corona and curtain :

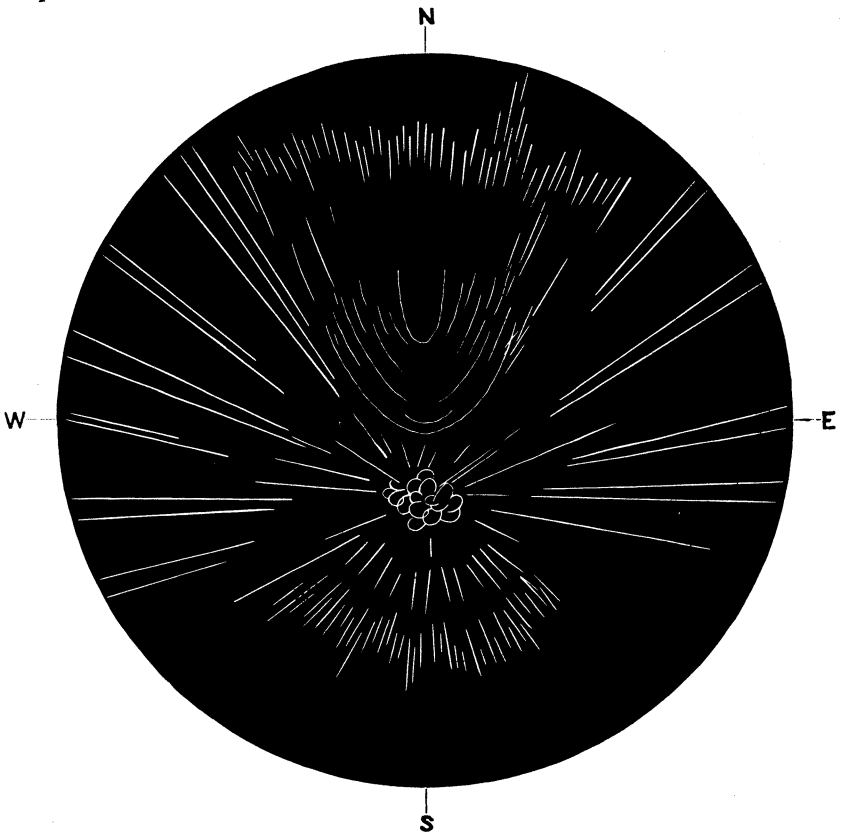


FIG. 1. AURORA AT 12.10 A. M.

A line passing through the centre of the corona and Polaris was the transverse axis of the hyperbolic curves, of which a mere suggestion is made in the diagram.

The corona itself was a somewhat elliptical crown of radiating streamers, within which was a permanent nebulous mass of light, having a *curdled* appearance. This inner curdled mass was continually moving and heaving like the sea, and was often traversed by dark rifts. It continually drifted eastward to vanish suddenly, and to be continually replaced by other cloud-like forms at the centre. Meanwhile the brilliant flashes of red light, disconnected, apparently, with the other phenomena, appeared

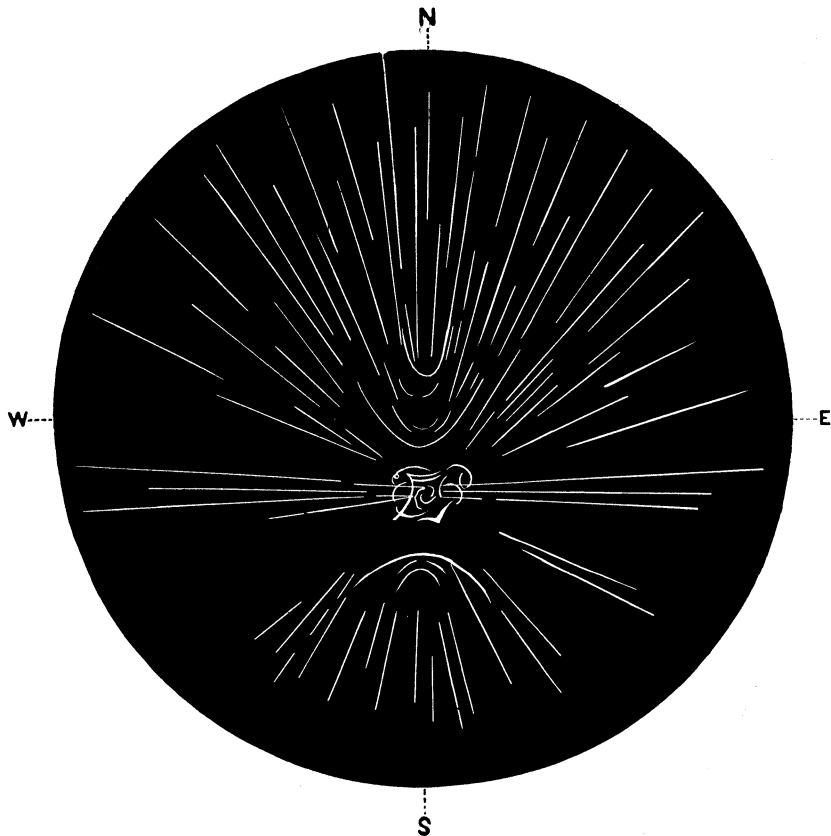


FIG. 2. AURORA AT 12.25 A. M.

in many portions of the sky, and often continued to form a back-ground for the quivering white streamers.

The streamers south of the corona presented quite a different appearance from those to the north. They were quite short, and were often broken into two or more segments, which fluctuated to and fro, but did not extend

lower than some thirty degrees above the southern horizon. At 12.20 Arcturus occupied almost the precise centre of the corona.

At 12.25 the remarkable sight was presented of two hyperbolic curves of light, the larger one lying in the north, the smaller to the south of the corona, and each pointing in an opposite direction to the other. The smaller hyperbola was bounded by an inverted arch of light in the south, some 30 degrees above the horizon. Straight lines of light, like a conjugate axis, passed east and west from the central point between the hyperbolas. The definite boundary of the southern auroral curtain may furnish data for a determination height of the aurora above the earth's surface. The appearance of the sky at this time is rudely represented in Fig 2.

It is evident that the phenomena now seen was no mere effect of perspective. The auroral streamers had become curved in obedience probably to the laws of magnetic force around a pole.

At 12.35 the corona was near R. A. 215° , Dec. $20^{\circ} 30'$, and at 12.45 near R. A. 216° , Dec. $20^{\circ} 30'$. At times the corona was a perfect star-like crown, with a small white cloud of light in the centre. Sometimes, however, it would vanish completely for a few moments, to reappear with greater brilliancy. The curdled cloudy matter within it occasionally took fantastic curved forms, and at the same time the surrounding streamers would form curves at their extremities close to the corona. Once the streamers above and below the corona moved for a short space slowly around it, in the direction of the hands of a clock.

At 1.05 A. M. the corona was estimated at R. A. 224° , Dec. 20° , and at 1.10 at R. A. 226° , Dec. 20° . By this time it had become fainter, and it frequently disappeared for a period. The aurora in the north continued until daylight. Special attention was directed to mapping at intervals during the continuance of the corona, its exact position among the stars, in order, if possible, to determine any proper motion of its own. The central point could always be determined by projecting the paths of streamers to their converging point.

The following map represents the approximate successive positions of the centre of the corona, and the time of each observation. With the exception of the position given for 11.40 P. M., which was estimated from memory, the positions here given are as plotted at the time upon the star-map.

Upon examination of this map it is at once evident that during the two hours in which it was observed, the corona had an eastward motion through space, and that this motion was at the rate of 15 degrees an hour, or precisely the direction and amount of the earth's rotation upon its axis. It was as if the corona had been fixed permanently to the earth, and the observation is a strong confirmation of the theory that the aurora is a truly terrestrial appendage.*

* The writer has previously (v. Proc. A. A. S., Boston, 1880, vol. xxix., p. 245), described a phenomenon noticed in the aurora of May 2, 1877, which, though less conclusively, leads to the same deduction. In that case an auroral comet-like streamer remained in a constant position, with regard to certain trees, for the space of nearly an hour, being apparently fixed to the earth like a great pointer, while the stars and the zodiacal light revolved past it.

The arc described by the corona was not perfectly coincident with a parallel of declination, but, if the observations are correct, had an inclination of somewhat over 2 degrees. The pole of this arc would be considerably west of the true north. Moreover the corona was always about 3 degrees east of the meridian, a fact also indicating that the radiant point of the streamers was west of north. The corona was constantly 18 to 20 degrees south of the zenith.

It is of interest to note in this connection that each of these facts has a direct relation to the position of the magnetic needle at Philadelphia. The magnetic pole is about 5 degrees west of the true pole, and the magnetic zenith is about $18\frac{1}{4}$ degrees south of the true zenith. The corona was, therefore, within one degree of the magnetic zenith. Parallax may, per-

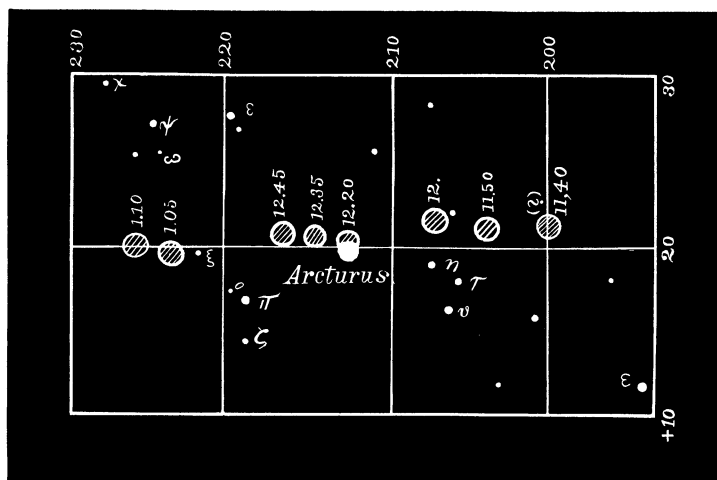


FIG. 3. MAP OF POSITIONS OF CORONA.

haps, account for the deviation, if any such exists. The position of the auroral streamers and of the corona is seen, therefore, closely to conform to the lines of magnetic force, and the connection between the two phenomena is evident.

The electrical effects of the aurora were very marked, confirming the belief that the aurora is an electrical or magnetic discharge through remote portions of our atmosphere. The telegraph wires over a large portion of the country were strongly affected by electrical currents. The wires leading from Chicago to New York, to Washington, to Milwaukee, and to Omaha, are stated to have been worked without batteries, and, after grounding the wires, messages to have been sent on the strength of the "auroral current" alone. The Atlantic cable suffered similar electrical disturbances.

The influence of an aurora upon the telegraph wires is very different from the local and transitory effects of a thunderstorm, and can always be recognized. The electrical disturbances at Philadelphia continued from midnight until eleven o'clock on Monday morning. At the office of the Western Union Telegraph Company in New York it is reported that the wires began to be affected soon after ten o'clock and that before eleven the wires in every direction were frequently interrupted. It is said that whenever an auroral current of like polarity with the battery reached the wires it neutralized the current completely and broke the circuit. In like manner auroral currents of opposite polarity, which were both powerful and frequent, would intensify the current to such a degree as to make it unsafe to use the wires. At such times brilliant sparks appeared at the ends of the keys and repeaters, which would soon burn the instruments if not disconnected. The change of polarity in the auroral current was very intermittent. Sometimes it occurred very rapidly; and at other times ten or fifteen minutes would intervene without change of current. Similar electrical phenomena are reported from many parts of the country, indicating an electrical storm of great extent.

There was no wind at Philadelphia during the aurora, and the mild spring-like weather before and during the few days since has undergone no change of consequence. Observations of this nature upon a number of auroras have led the writer to think that the popular idea that the aurora is either the cause or the result of change of weather is a fallacy. Local thunderstorms and several severe tornadoes have however occurred since the aurora in several parts of the country.

On the night of April 19-20 a second aurora appeared. There had been a severe thunderstorm early in the evening—the occasion of loss of life and property in different portions of the State—and some time after the sky had cleared, at about 1.30 A. M., there appeared a fine aurora, with high and bright streamers. As before, the telegraph wires were affected, the disturbance at Philadelphia continuing from 1 A. M. to 11.30 A. M.*

The occurrence of remarkable auroral displays at this time is a striking confirmation of the periodicity of those phenomena. It is just ten years since the last auroras of importance occurred, and the period of 10 to 12 years between maximum auroral displays may be regarded as firmly established. The coincidence of this period with that of most numerous sunspots shows a direct connection between the electrical condition of the earth and the sun. At the present time the sun is exhibiting remarkable disturbances. Upon the sun's disc are numerous and large spots which are continually changing in shape, and are traversed by solar cyclones of unusual energy. Large groups of sunspots are now visible to the naked

* The writer is indebted to the officers of the Western Union Telegraph Company for information. He also takes pleasure in acknowledging the kindness of Mr. T. F. Townsend, Signal Service Officer at Philadelphia, who has contributed his personal observations upon the aurora for use in the present paper.

eye, and one of the spots is said to be the largest which has appeared for ten years.

The theory is not improbable that sunspots are the result of solar electrical or magnetic storms, and that auroras are the result of a disturbed electrical condition of the earth, caused by induction from the sun. The common cause for both phenomena is probably cosmical.

Postscript.—Since this paper was presented, reports of an unusual auroral display have come from all sections of the country. The aurora was visible across the continent from the Atlantic to the Pacific coast. At San Francisco it is reported as the most brilliant seen for many years. A bright crimson light appeared at 8.30 P. M., and the aurora showed various colors. At Omaha a crimson sheet across the sky is described as its most remarkable feature. At Kansas City it was said to be the finest aurora since 1872, and at 12.30 the whole northern sky was lit up by streamers and red flames. At Warrenton, Mo., where it is described as the most remarkable ever seen, the light was so brilliant that signs 150 feet distant could be read. A white arch of light, extending from east to west, advanced southward at midnight to within 35 degrees of the southern horizon, and the corona was visible. At St. Louis it was seen early in the evening, and it is stated that at 11 P. M. there was no electrical disturbance in the telegraph wires. At Baltimore and Washington it was described as unusually fine, and consisting, first of a band of white light, later of shafts of colored light shooting through it, and afterwards of tremulous streamers moving with lightning rapidity, from north to south, while clouds of red fire hung in the northwest. At Richmond, Va., it was seen distinctly at 3 A. M., and is reported as the finest ever seen. At Boston, electrical disturbances were noticed shortly after the appearance of the aurora, and continued till late in the afternoon of the 17th. The wires from Boston to Albany and from Boston to New York were worked without the battery, that to New York having been worked by the auroral current alone for three hours consecutively.

In England, France, Belgium, Germany and Italy similar electrical perturbations were observed. Upon the French telegraphic lines the perturbations were so frequent from April 16th to April 20th that special measures were taken by the authorities to meet the contingency. Electrical equilibrium was restored on the 21st.

It is also of the greatest interest to learn that in England, where, so far as known, no aurora was seen, there occurred a great magnetic storm at the precise time that the aurora appeared in America. Mr. G. M. Whipple, of the Kew Observatory, in a communication to *Nature* of April 20, says "a magnetic storm of unusual intensity raged from about midnight of the 16th to midnight of the 17th," and that "a tremendous spot which appeared on the sun's disk on the 13th, is now rapidly approaching the central meridian, and a group observed on Saturday in advance of it, has undergone considerable change in the interval."

In *Nature* of April 27th, he further reports that "the magnetic disturbance began at 11.45 P. M. (6.45 P. M. Philadelphia time), April 16th, by an increase of the declination, an augmentation of the horizontal force and a diminution of the vertical force. The movements of the declinometer became gradually more rapid after 2 A. M. on the 17th (9 P. M. Philadelphia time), whilst its oscillations extended farther and farther from its normal position, principally in the direction of increased *westerly* declination. From 4.30 to 9 A. M. (11.30 P. M. to 4 A. M. Philadelphia time) the horizontal force had diminished so much that the trace frequently passed off the paper, and the register was lost for a while. The minimum of vertical force occurred at 5.55 A. M." (12.55 A. M. Philadelphia time). He states that the disturbance did not die out till about 8 P. M. on the 17th.

"During the 18th and 19th the magnets were unaffected, but at 3.45 A. M. of the

20th (10.45 P. M., April 19th, Philadelphia time), a second disturbance set in, commencing with a rapid increase of declination, the first swing of the magnet carrying it nearly a degree to the westward, whence it returned at 4.30 A. M. Its mean position was reached at 6 A. M. (1 A. M. Philadelphia time) and then its oscillations became very rapid, and continued so until 2 P. M., after which hour they became less. Both forces were also simultaneously disturbed, but their movements were much more limited than on Monday."

It is at once seen that there is a most remarkable coincidence in time between the magnetic storm in England and the aurora as seen here. The second magnetic storm also occurs simultaneously with the second aurora, and an absolute proof of the direct connection between the two phenomena is hereby established. It is interesting, also, to note that the magnetic disturbances for the most part slightly preceded the aurora, while on the other hand the electrical effects upon the telegraph wires were subsequent. This fact suggests magnetism as the primary cause of the aurora. The magnetic curves assumed by the streamers also favor this theory. The red flashes in the sky were probably accompanying electrical discharges, and many auroral effects may be due to the continual transmutation of the two forces.

Stated Meeting, May 5, 1882.

Present, 4 members.

Letters accepting membership were received from the Rev. Dr. Robins, No. 1821 Delancey Place, Philadelphia, April 26; from C. S. Sargent, dated Arnold Arboretum, Harvard University, Director's office, Brookline, Mass., April 26; from S. P. Sharples, A. M., No. 114 State street, Boston, April 29; from Franklin B. Hough, Department of Agriculture, Washington, D. C., May 2, and from George De B. Keim, No. 2009 Delancey Place, Philadelphia, April 25, 1882.

A photograph of M. Milne Edwards was received in a letter dated Museum d'Histoire Naturelle, Paris, April 7, with a request for Nos. 97, 102, 103 to complete a set of the Proceedings.

Letters of acknowledgment were received from the New Hampshire Historical Society (110); Museum of Comparative Zoölogy (110); American Antiq. Society (110); Rhode Island Historical Society (110); Connecticut Historical Society (110); Astor Library (110); New Jersey Historical Society (110);